

Mass Bounds for Flavour Mixing Bileptons

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Abstract

Mass bounds for doubly-charged bilepton gauge bosons are derived from constraints on fermion pair production at LEP and lepton-flavour violating charged lepton decays. The limit obtained of 740 GeV for the doubly-charged bilepton does not depend on the assumption that the bilepton coupling is flavour-diagonal, unlike other bounds which have been given in the literature.

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1 Introduction

Bileptons, gauge bosons carrying lepton number $L = 2$, [1] arise in a class of models in which the Standard Model gauge group $SU(3)_c \times SU(2)_L \times U(1)_Y$ is extended to $SU(3)_c \times SU(3)_L \times U(1)_X$, known as 331 Models. [2]-[7] Recently, a new lower limit on the mass of the doubly-charged bilepton of 850 GeV has been obtained from bounds on the conversion of muonium ($\mu^- e^+$) to antimuonium ($\mu^+ e^-$). [8] However, it has been noted [9, 10] that this limit relies on the assumption that the matrix V_Y which couples bileptons to ordinary leptons is at least approximately flavour diagonal, since the predicted conversion rate is dependent on the product $(V_Y^{11} V_Y^{22})$. It is therefore important to search for mass limits that allow for the possibility of more general coupling.

In particular, as will be discussed below, the scenario in which $V_Y^{11} \simeq V_Y^{22} \simeq 0$ does not appear to be in conflict with experimental data, and in this situation the muonium to antimuonium conversion rate would be zero, and so the 850 GeV mass limit would not apply.

The method to be employed here uses the fact that doubly-charged bileptons can contribute to electron - positron scattering by u -channel exchange, as first pointed out by Frampton and Ng [11], and also considered by Cuypers and Davidson [12]. Recently, new bounds on the mass scale of any exotic contributions to $e^+ e^- \rightarrow e^+ e^-$ have been obtained by the OPAL collaboration at LEP [14] which can thus be used to constrain the bilepton mass. Further, new limits on exotic contributions to $e^+ e^- \rightarrow \mu^+ \mu^-$ and $e^+ e^- \rightarrow \tau^+ \tau^-$ have also been obtained. These three processes have dependence on the matrix elements V_Y^{11} , V_Y^{12} and V_Y^{13} respectively. Since V_Y is unitary, an absolute bound on the bilepton mass can then be given, regardless of the nature of the coupling. In this manner, we find a lower bound on the doubly charged bilepton mass of 510 GeV.

This limit can be increased if data from lepton-flavour violating charged lepton decays is also taken into account, as these limits strongly constrain the form of V_Y . By combining these limits with the pair production data, the bilepton mass bound is able to be increased to 740 GeV.

2 Fermion Pair Production

For $M_Y \gg \sqrt{s}$ as is the case here, the process $e^+ e^- \rightarrow f \bar{f}$ may be treated by the four-fermion contact interaction formalism. In the usual parameterisation [13], the effective Lagrangian is given by

$$\mathcal{L}^{contact} = \frac{g^2}{(1+\delta)\Lambda^2} \sum_{i,j=L,R} \eta_{ij} [\bar{e}_i \gamma^\mu e_i] [\bar{f}_j \gamma_\mu f_j] \quad (1)$$

(where the symmetry factor $\delta = 1$ for $f = e$ and 0 otherwise). The coupling g in equation 1 is conventionally set to $g^2/4\pi = 1$.

A bilepton vertex is of the form

$$\frac{g_{3l}}{\sqrt{2}} \bar{l}_i^c \gamma_\mu \gamma_L V^{ij} l_j Y^{++} \quad (2)$$

writing $l = (e, \mu, \tau)$, leading to a four-fermion interaction:

$$V^{ij} V^{kl*} \frac{g_{3l}^2}{2M_Y^2} \bar{l}_i^c \gamma^\mu \gamma_L l_j \bar{l}_l \gamma_\mu \gamma_L l_k^c \quad (3)$$

$$= V^{ij} V^{kl*} \frac{g_{3l}^2}{2M_Y^2} \bar{l}_i^c \gamma^\mu \gamma_L l_k^c \bar{l}_l \gamma_\mu \gamma_L l_j \quad (4)$$

$$= -V^{ij} V^{kl*} \frac{g_{3l}^2}{2M_Y^2} \bar{l}_k \gamma^\mu \gamma_R l_i \bar{l}_l \gamma_\mu \gamma_L l_j \quad (5)$$

Expressing this in the form of equation 1 gives $\eta_{RL} = \eta_{LR} = +1$ (the negative sign from the Fierz transformation cancelling with an overall negative sign due to the relative ordering of the fermion fields [11]) with couplings given in the three cases by:

$$\begin{aligned} e^+ e^- \rightarrow e^+ e^- \quad \eta_{LR} \quad \frac{g^2}{\Lambda^2} &= \frac{g_{3l}^2}{2M_Y^2} |V_Y^{11}|^2 \\ \eta_{RL} \quad \frac{g^2}{\Lambda^2} &= \frac{g_{3l}^2}{2M_Y^2} |V_Y^{11}|^2 \\ e^+ e^- \rightarrow \mu^+ \mu^- \quad \eta_{LR} \quad \frac{g^2}{\Lambda^2} &= \frac{g_{3l}^2}{2M_Y^2} 2|V_Y^{12} V_Y^{21}| \\ \eta_{RL} \quad \frac{g^2}{\Lambda^2} &= \frac{g_{3l}^2}{2M_Y^2} (|V_Y^{12}|^2 + |V_Y^{21}|^2) \\ e^+ e^- \rightarrow \tau^+ \tau^- \quad \eta_{LR} \quad \frac{g^2}{\Lambda^2} &= \frac{g_{3l}^2}{2M_Y^2} 2|V_Y^{13} V_Y^{31}| \\ \eta_{RL} \quad \frac{g^2}{\Lambda^2} &= \frac{g_{3l}^2}{2M_Y^2} (|V_Y^{13}|^2 + |V_Y^{31}|^2) \end{aligned} \quad (6)$$

For convenience the approximation will now be made that $|V_Y^{ij}| = |V_Y^{ji}|$, experimentally justified by the charged lepton decay limits discussed below. The combined limit Λ_{LR+RL} can then be used rather than the separate limits $\Lambda_{LR} = \Lambda_{RL}$. Specialising to the 331 Model, the bilepton coupling g_{3l} will be set to $g = e/\sin \theta_W$.

The limits then obtained are shown in table 1.

Consideration of this data alone gives a lower limit on the bilepton mass of $M_Y > 512 \text{ GeV}$ with $|V^{11}| = 0.66$, $|V^{12}| = 0.59$ and $|V^{13}| = 0.46$, however this limit can be made more restrictive by including additional experimental data.

Process	Mass Scale	Bilepton Mass Limit
$e^+e^- \rightarrow e^+e^-$	$\Lambda > 6.2\text{TeV}$	$M_Y > V^{11} 770\text{GeV}$
$e^+e^- \rightarrow \mu^+\mu^-$	$\Lambda > 4.9\text{TeV}$	$M_Y > V^{12} 860\text{GeV}$
$e^+e^- \rightarrow \tau^+\tau^-$	$\Lambda > 6.3\text{TeV}$	$M_Y > V^{13} 1110\text{GeV}$

Table 1: Limits on mass scale of new contact interaction [14] and corresponding bilepton mass limit (95% C.L.)

3 Charged Lepton Decay Limits

Information on the form of V_Y can be deduced from limits on the exotic decays of μ and τ into three charged leptons, that is $\mu^- \rightarrow e^+e^-e^-$ and $\tau^- \rightarrow l_1^+l_2^-l_3^-$, where $l_i = e, \mu$. [7, 12] Such decays could be mediated by bileptons with appropriate couplings, however current experimental limits on the branching ratio for these decays are 1×10^{-12} for muon decays, [15] and of the order 10^{-6} for the various tau decays. [16]

These limits clearly are compatible with low-mass bileptons only if the coupling matrix is either almost diagonal, that is:

$$|V_Y^{ij}| \simeq \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (7)$$

or of the form

$$|V_Y^{ij}| \simeq \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (8)$$

in which mixing between the first two generations is maximal. Of course though, V_Y becomes less restricted as the value of M_Y is increased. (An interesting question we do not consider here is that of the naturalness of these forms for V_Y).

In particular, limits on the decays $\mu^- \rightarrow e^+e^-e^-$, $\tau^- \rightarrow e^+e^-e^-$ and $\tau^- \rightarrow e^+\mu^-e^-$ respectively lead to the following constraints:

$$\left(\frac{M_W}{M_Y}\right)^4 (|V_{12}|^2 + |V_{21}|^2) |V_{11}|^2 < 1.0 \times 10^{-12} \quad (9)$$

$$\left(\frac{M_W}{M_Y}\right)^4 (|V_{13}|^2 + |V_{31}|^2) |V_{11}|^2 < 1.7 \times 10^{-5} \quad (10)$$

$$\left(\frac{M_W}{M_Y}\right)^4 (|V_{13}|^2 + |V_{31}|^2) (|V_{12}|^2 + |V_{21}|^2) < 1.0 \times 10^{-5} \quad (11)$$

A bilepton mass limit can then be obtained for each of the two possible forms of V_Y (equations 7 and 8) by requiring that the limits from table 1 and from equations 9-11 are all satisfied, consistent with V_Y being unitary.

For flavour-diagonal coupling (equation 7) the limit obtained in this manner is

$$M_{Y--} > 740\text{GeV} \quad (12)$$

with $|V_Y^{11}| = 0.97$, while for the case of maximal mixing between the first and second generations (equation 8) the limit is

$$M_{Y--} > 860\text{GeV} \quad (13)$$

with $|V_Y^{12}| = 0.99$.

4 Conclusion

A lower bound on the mass of the doubly-charged bilepton has been obtained of

$$M_{Y--} > 740\text{GeV} \quad (14)$$

from consideration of experimental limits on fermion pair production in electron-positron collisions and lepton-flavour violating charged lepton decays. While this limit is less stringent than that obtained from muonium-antimuonium conversion, it is more general, as it does not depend on any assumptions about the form of the bilepton mixing matrix.

This value may also be compared with the mass bound on the singly charged bilepton of 440 GeV [17] obtained from consideration of muon decay parameters, and which is also independent of the form of V_Y .

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